EFFECTS OF CS AGENTS ON VEGETATION. II. FIELD AND SCREENING STUDIES

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Aberdeen Proving Ground, Maryland

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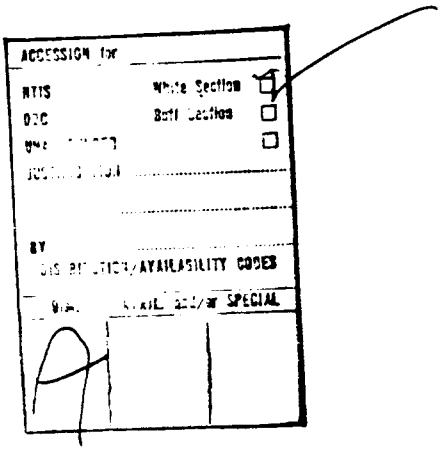

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CS-1 applied to branches of six woody species caused greatest damage when plants were in immature foliage. Four herbaceous species grown in soil with incorporated CS-1 showed maximum seedling damage when agent applications were made within four weeks prior to planting. Greenhouse screening tests on 29 woody and 41 herbaceous species at dosages of 5.6 and 28 kg/ha showed the herbaceous group to be more susceptible to foliar damage than woody species and to exhibit a greater range of variability in effects of CS-1. Only three woody species

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20. ABSTRACT (Contd)

showed foliar damage in excess of 20% from treatment at the high dosage: eight herbaceous species had greater than 50% damage at the corresponding dosage. Cereal grains and conifers appeared to be more resistant to damage than other plants tested.

SUMMARY

Field and greenhouse screening studies were conducted to determine the effects of riot control agent, CS-1, on vegetation. In the field studies, low-dosage rates selected were representative of those occurring in close proximity to sources of dissemination in civil disorder situations. High-dosage levels were within the limits recommended for terrain denial in military operations.

CS-1 applied to branches of six woody species caused greatest damage when plants were in immature foliage. Four herbaceous species grown in soil with incorporated CS-1 showed maximum seedling damage when agent applications were made within four weeks prior to planting.

Greenhouse screening tests on 29 woody and 41 herbaceous species at dosages of 5.6 and 28 kg/ha showed the herbaceous group to be more susceptible to foliar damage than woody species and to exhibit a greater range of variability in effects of CS-1. Only three woody species showed foliar damage in excess of 20% from treatment at the high dosage; eight herbaceous species had greater than 50% damage at the corresponding dosage. Cereal grains and conifers appeared to be more resistant to damage than other plants tested.

PREFACE

The work described in this report was authorized under Task 1W5620605AD2802, Work Unit 001, Special Projects. The work was started in March 1972 and completed in June 1973. The experimental data are contained in notebook TSD 8675.

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I. INTRODUCTION.

Studies were made by the Vegetation Control Division to determine the effects of CS-1 on woody and herbaceous species under field and greenhouse conditions. Preliminary greenhouse and laboratory studies with CS agents were summarized by A. R. Templeton, et al.[1]

Field studies were conducted in 1972 on established woody plants and on planted herbaceous crop species. Final observations on woody species were completed during the growing season of 1973 so that possible long-term effects might be observed. Screening studies were conducted under greenhouse conditions in late 1972 and early 1973 to evaluate the effects of CS-1 on a wide range of woody and herbaceous species used in ornamental plantings and gardens.

II. METHODS.

A. Materials.

CS-1 was selected for use in all field and greenhouse tests involving CS agents. CS-1 contains approximately 5% silica aerogel which provides antiagglomerative properties.

Preliminary trials indicated that the amounts of CS at the ICt50 for personnel (10 to 20 mg/cu m)[2] did not cause appreciable responses of test plants. However, in civil disorder situations, the levels of CS agents near the sources of dissemination are often much greater than the ICt50. Accordingly, the low-dosage rate selected for the field studies was equivalent to that occurring in close proximity to sources of dissemination. The corresponding high-dosage levels selected for the vegetation tests were within the upper limits recommended for terrain denial in military situations.

B. Field Studies.

All field studies were conducted in the field research area of the Vegetation Control Division at Fort Detrick.

1. Woody Species. Established plantations of 10- to 14-year-old plants of the following species were used for foliar application tests:

Norway maple, *Acer platanoides* L.

Flowering dogwood, *Cornus florida* L.

[1] Templeton, A. R., See, R. M., Morrison, B. W., and Dralle, D. L. EATR 4773 Effects of CS Agents on Vegetation: I. Greenhouse and Laboratory Studies. August 1973. UNCLASSIFIED Report.

[2] Edgewood Arsenal. Characteristics of Riot Control Agent CS. EASP 600-1, October 1967. UNCLASSIFIED Report.

Lombardy poplar, *Populus nigra* L. var. *italica* Muench.

Scotch pine, *Pinus sylvestris* L.

California privet, *Ligustrum ovalifolium* Hassk.

Chinese elm, *Ulmus parvifolia* Jacq.

Initially, treatments were scheduled for application at dormant bud, immature foliage, and mature foliage growth stages but at the time the first treatments were started, growth had already started on most woody species. Treatments were made on Norway maple in the dormant bud stage. Treatments at both low and high dosages were applied to 10 individual branches selected from three trees for each dosage level. The individual branch was enclosed in a 30- by 45-cm polyethylene bag and the desired dosage of CS-1 added. Homogeneous treatment was obtained by gently shaking and then removing the bag from the branch.

Effects on woody species were determined by measurements of the apical growth of the main branch over a 3-month period and by estimations of percent leaf damage such as necrosis and deformation at the end of 4 weeks.

2. **Herbaceous Species.** Plantings were made of the following herbaceous species to test the effects of soil-incorporated CS-1.

Soybean, *Glycine max* (L.) Merr. var. Kanrich

Radish, *Raphanus sativus* L. var. Scarlet Globe

Bean, *Phaseolus vulgaris* L. var. Red Kidney

Millet, *Pennisetum glaucum* L. var. Pearl

Experience with woody species indicated the downwind hazard generally would be too great for foliar treatment of herbaceous species; therefore, applications were made by incorporation of CS-1 in soil prior to planting to determine its effects on emergence and yield. Treatments were made at two dosage levels (55 and 270 kg/ha) at 8, 4, and 0 weeks prior to planting. Ten replications were used for each treatment and corresponding control. Each replication consisted of a 5- by 10-ft plot including a single 5-ft row of each of four herbaceous species. CS-1 was incorporated into the soil by spreading it uniformly into four evenly spaced trenches in each 5- by 10-ft plot and covering with soil. Plots treated at 8 and 4 weeks before planting were disked after soil incorporation to distribute the CS-1 in the soil and to control weed growth. Plots treated on the day of planting (0 week) were not disked. As the location of the soil-incorporation trenches coincided approximately with the planting rows, the concentration of agent in the 0-week treatments was undoubtedly greater than in the 4- and 8-week treatments.

The responses were measured by counting the numbers of plants emerged and by determining plant yields per plot.

3. **Weather Information.** A field weather station was established near the test plots and temperature, humidity, wind velocity and direction, and precipitation were continuously recorded during the period of April to October 1972. Wind direction and velocity were observed prior to each field application to ensure that CS-1 drift was not a threat to nearby office and residential areas. Treatments were conducted only when wind velocities were less than 3 mph.

C. Greenhouse Screening.

Seventy ornamental and crop species were treated with CS-1 in acetone solution and observed under greenhouse conditions. The plants were established in soil in 10- by 10-cm plastic pots and treatments made in a laboratory spray cabinet available at Vegetation Control Division.[3]

Dosage rates of 5.6 and 28 kg/ha were established after preliminary trials had shown that selected herbaceous species were significantly but not completely damaged at these dosages. The quantity of CS-1 needed to cause measurable damage was much less than under field conditions since the acetone apparently resulted in a more homogeneous contact and favored the retention of CS on the plant surfaces. Application volumes of 10 ml were used on an area of 30 by 60 cm. Treatment of each species with acetone checks gave little or no plant response and the data are not included. Ten replications were used for the high- and low-dosage levels and for the controls for each species.

Immediately after treatment, plants were randomly placed on greenhouse benches and observed at 24 hours and at 7 and 14 days. Ratings of plant damage were based on visual observations of overall effects and expressed as total damage on a scale of 0-100 percent.[3] Specific types of damage such as necrosis, chlorosis, and formative effects were noted at each observation period.

III. RESULTS.

A. Foliar Applications on Woody Plants.

The general responses of woody plants to CS-1 are summarized in table 1 as percent leaf damage observed at 4 weeks and terminal branch growth in the 3 months following treatment. Data are presented for treatments at the immature and mature foliage stages; treatment during the dormant bud stage was restricted to one species, Norway maple. High-dosage levels applied to Norway maple at this stage resulted in darkened bud scales as observed 4 weeks later but branch growth appeared to be normal at the end of 3 months.

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[3] Frank, J. R., Creager, R. A., and Jacobs, L. M. A Laboratory Spray Cabinet for Herbicides and Growth Regulators. Weed Science *20*, 170-172 (1972).

Table 1. Effects of Foliar Applications of CS-1 on Woody Species*

Species	Damage at 4 weeks			Branch growth at 3 months		
	0	8.8 gm/m^3	60	0	8.8 gm/m^3	60
		%			cm	
Immature Foliage						
Chinese elm	0	48 ± 6	62 ± 2	34 ± 4	13 ± 3	12 ± 3
Dogwood	0	42 ± 2	76 ± 2	24 ± 3	18 ± 2	19 ± 2
Privet**	0	50 ± 0	80 ± 0	18 ± 2	11 ± 2	6 ± 1
Norway maple	0	18 ± 6	100	23 ± 3	15 ± 2	0
Mature Foliage						
Chinese elm	0	39 ± 8	81 ± 2	–	–	–
Dogwood	0	27 ± 7	66 ± 8	–	–	–
Norway maple	0	14 ± 6	31 ± 9	–	–	–

* Data represent the mean and mean standard error of 10 replications.
** Damage estimates based on leaf curl.

Data in table 1 from treatment in the immature foliage condition show appreciable leaf damage in observations at 4 weeks but a lesser response or effect on terminal growth as measured 3 months after treatment. Norway maple appeared to be the most sensitive species with complete damage at 4 weeks and no terminal growth occurring from the heavier dosage level. Observations 24 hours after application of CS-1 showed foliage of both Chinese elm and dogwood to have necrotic spots and darkened areas. Privet exhibited a different response with extreme curling of leaves that were fully formed at the time of treatment. Immature leaves formed subsequent to treatment were characterized by increased size of veins and by thicker and darker leaf margins. Observations at 3 months revealed that the curled leaves had remained alive and foliage developing later appeared to be normal.

Treatments made when plants had attained mature foliage caused appreciable damage only at the high-dosage level. Chinese elm and dogwood exhibited greater susceptibility than Norway maple. Additional observations on Lombardy poplar not included in the table showed no visible leaf damage occurred at either high or low dosages during the 3 months after treatment.

Scotch pine had a slight inhibition of apical growth when measured 3 months after treatment but since a very high dosage (120 gm/cu m) was used and a considerable amount of the CS-1 powder remained on the plants, the effects were not considered significant.

B. Soil-Incorporated Treatments on Herbaceous Plants.

Comparative data on the number of plants emerging when planted at 0, 4, and 8 weeks after soil incorporation of CS-1 are shown in table 2 for four species. Radish appeared to be most susceptible to CS-1, showing highly significant reduction in the numbers of emerging seedlings from the high-dosage level applied at the time of planting or at 4 weeks previous to planting. A significant reduction in soybean seedlings resulted from high-dosage levels made at 0 to 8 weeks. No effect was obtained on emerging seedlings of kidney bean whereas millet showed some reduction when CS-1 was applied at the day of planting.

Table 2. Effects of Soil-Incorporated CS-1 on Numbers of Emerging Seedlings[a]

Treatment		Kidney bean	Soybean	Radish	Millet
Rate	Weeks prior to planting				
kg/ha					
Control		5 ± 1	5 ± 1	24 ± 2	11 ± 1
	0	5 ± 1	4 ± 1	10 ± 2	5 ± 1
55	4	4 ± 1	3 ± 1	20 ± 2	8 ± 1
	8	5 ± 1	5 ± 1	23 ± 4	14 ± 1
	0	3 ± 1	2 ± 0	2 ± 1	4 ± 1
270	4	4 ± 0	2 ± 0	9 ± 3	10 ± 1
	8	5 ± 1	2 ± 1	14 ± 4	10 ± 1

[a] Data represent mean and mean standard error per plot.

Because of bird and rodent damage to seedlings subsequent to treatment, valid data on plant yields were obtained only in the case of radish, a susceptible species (table 3). In radish, significant reductions in fresh weight of tops and roots resulted from the low-dosage level only when CS-1 was applied at the time of planting. At the high dosage, both tops and roots showed appreciable reduction when CS-1 was applied at periods up to 8 weeks prior to planting.

C. Greenhouse Screening.

Evaluations of the effects of CS-1 in acetone solution applied to the foliage of 29 woody plants and 41 herbaceous species are given in tables 4 and 5.

Table 3. Effects of Soil-Incorporated CS-1 on Fresh Weight of Radish*

Rates	Time of treatment before planting	Tops	Roots
kg/ha	wk	gm	
Control		117 ± 22	213 ± 27
55	0	37 ± 13	67 ± 23
	4	117 ± 18	207 ± 30
	8	122 ± 26	186 ± 29
270	0	8 ± 3	12 ± 5
	4	42 ± 12	71 ± 22
	8	46 ± 14	76 ± 23

* Data represent mean plot weight and mean standard error in gms.

Only 10 of the 29 woody species exhibited more than 10% damage from treatment at the higher dosage level (28 kg/ha). Rose-of-Sharon was the most susceptible species with a rating of 31% at 7 days. Foliar damage from the low-dosage level did not exceed 20% and in only four species was it greater than 10%.

In the 41 herbaceous species tested, foliar damage exceeded 50% in eight species from applications at the high-dosage level. Black Valentine bean and radish were the most sensitive species tested and foliar damage of these species exceeded 90% at the high-dosage level. Radish also exhibited greater than 90% damage from treatment at the low dosage. Plants showing little or no effect from CS-1 included the cereals (wheat, rice), onion, carrot, cabbage, pea, and yarrow.

IV. DISCUSSION.

The results of field applications of CS-1 on woody plants indicated that plants in a vigorously growing condition with immature foliage sustained greater leaf damage than plants with mature foliage and in which apical growth had terminated. Limited tests in the dormant season on Norway maple appeared to have little or no effect on the dormant buds.

The woody species tested varied in sensitivity to foliar treatments. Scotch pine, a representative conifer, was relatively insensitive to CS-1. Deciduous species such as Chinese elm, dogwood, and Norway maple exhibited varying amounts of leaf damage at the rates of application in these tests.

Table 4. Foliar Damage (%) from CS-1 Applied in Acetone on Woody Plants as Evaluated at 1 to 7 Days after Treatment

Species	Damage	
	5.6 kg/ha	28 kg/ha
	%	
Abelia grandiflora **Rehd., abelia**	0-5	0-5
Acer rubrum **L., red maple**	5-10	10-20
Albizzia julibrissin **Durazz., mimosa**	0-5	5-10
Berberis thunbergii **DC., Japanese barberry**	0-5	5-10
Betula alba **L., white birch**	0-5	10-20
Calycanthus floridus L., sweet shrub	5-10	10-20
Celtis occidentalis L., hackberry	0-5	10-20
Cercus occidentalis L., redbud	0-5	10-20
Crataegus oxyacantha L., English hawthorn	0-5	0-5
Deutzia scabra Thunb., deutzia	0-5	5-10
Elaeagnus angustifolia L., Russian olive	10-20	20-30
Forsythia suspensa Vahl, forsythia	0-5	5-10
Ginkgo biloba L., ginkgo	0-5	0-5
Hibiscus syriacus L., rose-of-Sharon	10-20	30-40
Ilex crenata Thunb., Japanese holly	0-5	0-5
Lagerstroemia indica L., crepe myrtle	10-20	10-20
Ligustrum ovalifolium Hassk., California privet	0-5	0-5
Liriodendron tulipifera L., tulip tree	5-10	10-20
Lonicera tatarica L., Tatarian honeysuckle	0-5	5-10
Malus floribunda Sieb., showy crabapple	0-5	0-5
Pieris japonica D. Don, pieris	0-5	0-5
Pinus strobus L., white pine	0-5	0-5
Platanus occidentalis L., sycamore	0-5	0-5
Spiraea vanhouttei Zabel, spiraea	0-5	0-5
Syringa vulgaris L., lilac	0-5	0-5
Tilia americana L., basswood	10-20	20-30
Tsuga canadensis (L.) Carr., hemlock	0-5	0-5
Ulmus parvifolia Jacq., Chinese elm	0-5	0-5
Viburnum tomentosum Thunb., Japanese snowball	0-5	0-5

Table 5. Foliar Damage (%) from CS-1 Applied in Acetone on Herbaceous Plants as Evaluated 1 to 7 Days after Treatment

Species	Damage	
	5.6 kg/ha	28 kg/ha
	%	
Achillea millefolium L., yarrow	0-10	0-10
Ageratum houstonianum Mill., ageratum	0-10	20-30
Allium cepa L., onion	0-10	0-10
Althaea rosea Cav., hollyhock	0-10	10-20
Arachis hypogaea L., peanut	10-20	10-20
Beta vulgaris L., beet	10-20	10-20
Brassica oleracea L., cabbage	0-10	0-10
Brassica rapa L., turnip	30-50	50-70
Browallia speciosa Hook., browallia	0-10	10-20
Campanula medium L., Canterbury bells	10-20	20-30
Capsicum annuum L., pepper	0-10	0-10
Celosia cristata L., cockscomb	0-10	10-20
Citrullus vulgaris Schrad., watermelon	10-20	20-30
Cucumis sativus L., cucumber	0-10	10-20
Cucumis melo L., cantaloupe	20-30	50-70
Cucurbita sp., squash	10-20	10-20
Daucus carota L., carrot	0-10	0-10
Glycine max L., soybean	0-10	20-30
Hibiscus esculentus L., okra	10-20	30-50
Iberis sempervirens L., candytuft	0-10	50-70
Ipomoea purpurea (L.) Roth, morningglory	50-70	70-90
Lupinus polyphyllus Lindl., lupine	0-10	30-50
Lycopersicum esculentum Mill., tomato	20-30	50-70
Nicotiana sp., flowering tobacco	30-50	30-50
Oryza sativa L., rice	0-10	0-10
Pastinaca sativa L., parsnip	0-10	10-15
Petunia sp., petunia	0-10	10-20
Phaseolus lunatus L., lima bean	0-10	10-20
Phaseolus vulgaris L., Valentine bean	50-70	90-100
Phaseolus vulgaris L., kidney bean	30-50	70-90
Pisum sativum L., pea	0-10	0-10
Poa pratensis L., Kentucky bluegrass	0-10	20-30
Portulaca grandiflora Hook., portulaca	0-10	20-30
Raphanus sativa L., radish	90-100	90-100
Solanum melongena L., eggplant	10-20	30-50
Tagetes vulgare L., marigold	0-10	20-30
Triticum vulgare L., wheat	0-10	0-10
Tropaeolum sp., nasturtium	20-30	30-50
Viola tricolor L., pansy	0-10	20-30
Vinca minor L., periwinkle	0-10	10-20
Zea mays L., corn	0-10	10-20

The effects of CS-1 appear to be almost entirely due to contact damage. The only evidence of translocation or systemic action was noted in California privet in which leaf malformations subsequent to treatment were apparent for approximately three months.

Long-term effects on woody plants as observed during the growing season one year after treatment were attributed only to damage incurred at the time of exposure to CS-1. Leaf damage or growth stoppage of treated branches was often masked or obliterated by new growth which took place during the same growing season and in most cases by the onset of the next growing season.

The field studies indicated that environmental conditions might influence the possible effects of CS agent. For example, retention of the CS-1 powder was decreased as a result of heavy precipitation because of high winds following application but was augmented under the dew conditions prevailing in early morning treatments.

The effects of soil-incorporated CS-1 varied with species but in most cases a significant reduction in the numbers of emerging seedlings occurred when the agent was incorporated into the soil within 4 weeks prior to planting. The effects of the agent were hardly evident when incorporated 8 weeks before planting. As in the laboratory and greenhouse studies previously reported,[1] radish was one of the more sensitive species to CS-1 in its effect on germination and emergence. Millet showed little effect from soil-applied CS except when applied at the date of planting.

The greenhouse screening tests showed that: (1) herbaceous species as a group were more sensitive to CS-1 than woody species; (2) a wide variability in sensitivity was exhibited within both the woody and herbaceous groups. Except for a few herbaceous species, all treated plants showed recovery from leaf damage starting at about the 14th day after treatment. This decrease in effect was associated with the continued growth of plants with no indications of damage to growth made subsequent to treatment. Cereal grains showed little or no effect of CS-1 in the dosage rates employed. The broadleaf or dicotyledonous herbaceous species showed a broad range of sensitivity. No generalizations could be made for the woody plants other than the negligible response of the conifers tested (white pine and hemlock).

V. CONCLUSIONS.

Field and greenhouse studies on woody and herbaceous plants showed a wide variability in foliar damage and reduction in shoot growth from applications of CS-1 in powder form. Applications of CS-1 at dosages several hundredfold that of the ICt50 for personnel caused foliar damage and reduced shoot growth of woody plants. High dosages equivalent to that used in terrain denial in military situations (60 to 120 gm/cu m) caused significant damage to the leaves of woody plants.

Incorporation of CS-1 in soil at 0 to 8 weeks prior to planting produced variable results on four herbaceous crop species. Radish was the most susceptible plant tested with significant reductions in emergence and growth when high dosages were applied at planting or up to 4 weeks prior to planting.

In screening tests on 70 species, herbaceous plants were more susceptible to foliar damage and exhibited greater variability in response than woody plants. Cereal grains and conifers appeared to be more resistant to foliar damage than other plant groups tested.